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OPREDELENIE SIL SMERZANNIIA GRUNTA S DEREVOM I BETONOM I
SOPROTIVLENNIIA SDVIGU MERZLYKH GRUNTOV V POLEVYKH USLOVIIAKH

(DETERMINATION OF ADFREEZING STRENGTH OF WOOD AND
CONCRETE TO GROUND AND SHEAR STRENGTH OF FROZEN
GROUND UNDER FIELD CONDITIONS)

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KOMITET PO VECHNOI MERZLOTE

(COMMITTEE ON PERMAFROST)

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OPREDELENIE SIL SMERZANIYA GRUNTA S DEREVOM I BETONOM I
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(Determination of Adfreezing Strength of Wood and Concrete to Ground and
Shear Strength of Frozen Ground Under Field Conditions)

by

L. A. Meister and P. I. Mel'nikov

Experiments to determine the adfreezing strength of wood and concrete to ground and the shear strength of frozen ground were conducted at the Igarka Permafrost Station during the first half of 1938. The purpose of these tests was to transfer experimentation along these lines to field conditions, and determine from the outset at least some idea of the degree to which the laboratory findings corresponded to the situation in nature.

In point of fact, the limited data already at hand with regard to these properties of frozen ground had been obtained as a result of laboratory experiments with samples of small size and consisting of artificially prepared soil specimens. Under those conditions, the importance of various factors might be notably different than in the field. This would reflect the degree to which data obtained from such laboratory tests could be accepted.

Conducting these experiments at the Igarka Permafrost Station had the advantage of: (1) providing ground under natural conditions and (2) providing large surfaces for adfreezing and shear strength tests, 5,490 square centimeters for the former, and 800 square centimeters for the latter.

Hitherto, all significant efforts to determine the physical and mechanical properties of frozen ground had been conducted in the Soil Mechanics Laboratory of the Leningrad Institute of Public Utilities Engineers (L.I.I.K.S.), in cooperation with the Permafrost Committee of the U.S.S.R. Academy of Sciences, under N. A. Tsytoich.¹

The researches conducted at Igarka constitute the beginning of field work by the Igarka Permafrost Station of the Northern Sea Route Administration, also jointly with the Permafrost Committee of the U.S.S.R. Academy of Sciences. It is intended to continue these studies in future years. The transfer of the Igarka Permafrost Station to the Permafrost Committee will probably cause further improvement in the organizational setup of the work.

The experiments to determine the adfreezing strength and shear strength of frozen ground under field conditions were conducted under the direct guidance of S. D. Balatsenko, manager of the permafrost station.

I. Experiments to Determine Adfreezing Strength of Ground to Wood and Concrete

We shall not define "adfreezing strength" here since it has been set forth clearly in the special literature on that subject (see footnote 1). We shall, therefore, proceed directly to describe the methods of the experiments themselves.

Posts of wood and concrete were set into the ground of the test plot at the Igarka Permafrost Station in July and August 1937. The adfreezing strength was to be determined by establishing the force needed to extract these posts from the ground in winter after the ground with which they were in contact had had the opportunity to freeze solid.

The wooden posts were prepared as follows. Sections of round timber, approximately 2 meters long and 0.2 to 0.3 meter in diameter were thoroughly cleaned and dressed with a hatchet. Then two flat surfaces were shaped with the hatchet on opposite sides of the timber for a distance of about half its length, so that a collar of bar iron could be fitted snugly. Then the half-length was drilled at five or six places, perpendicular to the plane surface, for bolts. It was these bolts that held the collar firmly to the timber. Figure 1 is a drawing of this arrangement. At the time of setting, the wooden posts were air-dry.

The reinforced-concrete posts were square in section. Crushed stone was added to the aggregates for the concrete to be poured into the centers of these posts. The reinforcements rested in the center of the posts. The perimeter of each post was roughly 90 centimeters. Figure 2 shows a front and top view of the design.

To place the posts, holes of the following dimensions were dug on the test field. In sand, the hole was 100 centimeters square and 50 or 60 centimeters deep. Holes in silt-dust soil measured 50 centimeters in each direction. To prevent the bottom faces of the posts from adfreezing, they were liberally covered with grease. The posts were then placed in the middle of the holes, at a depth of about 50 centimeters. The holes were then backfilled with the local soil, and lightly tamped. In other words, the procedure followed was such as to create conditions similar to those existing on construction sites.

1. N. A. Tsytoich and M. I. Sumgin. Osnovaniya mekhaniki merzlykh gruntov (Basic Frozen Ground Mechanics), Academy of Sciences, Moscow-Leningrad, 1937; Laboratornye issledovaniya mekhanicheskikh svoystv merzlykh gruntov. Sbornik I (Laboratory Studies of the Mechanical Properties of Frozen Ground. Series I), Academy of Sciences, Moscow-Leningrad, 1936.

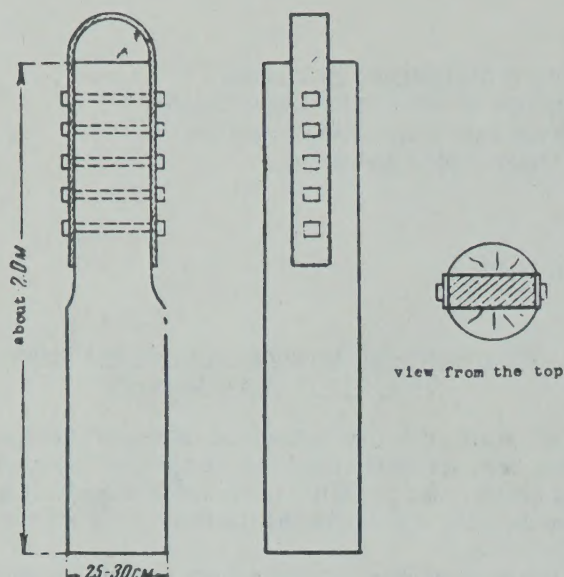


Fig. 1. Plan of wooden post as prepared for experiment.

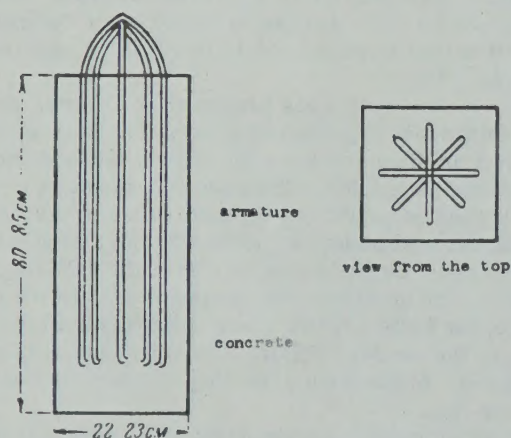


Fig. 2. Plan of concrete post as prepared for experiment.

The extraction of the posts began in March 1938, more than six months after they had been emplaced.

It is to be noted that the application of considerable force, reaching 30 tons in some cases, was needed to extract these posts. This caused much difficulty and required considerable time. A single experiment for the extraction of one post required four men, laboring an eight-hour day.

The extraction was performed by means of a lever with an arm ratio of 1:7 or 1:8. The setting up of a lever capable of exerting such considerable force proved quite a difficult task. The #30 I-beam originally used bent under the stress (see Fig. 3).

As a result, that lever had to be replaced by a stronger one. A larchwood timber, 54 centimeters in diameter and 8 meters long, was used and proved adequate for all further efforts (see Fig. 4).

Temperatures were measured at three points: ground level, 25 centimeters deep, and 50 centimeters deep. Angular bore holes were sunk to within 5 centimeters of the middle and bottom of each post. Delayed psychrometric thermometers were used (see Fig. 5).

The temperatures recorded were different at all three points, unlike those found in the laboratory, where more or less identical temperatures were obtained over the whole area. Thus, the experiments were under conditions more closely resembling those encountered in nature, where ground temperatures vary according to depth, due to air temperature and other factors.

The motion of the posts during extraction was measured by L.I.I.K.S. deflectometers accurate to 0.01 mm. After the experiments, samples were taken from the walls of the holes for the purpose of determining moisture content and volume weight.

As we have already stated, the adfreezing strength of ground to wood and concrete was tested in sand and silt-dust soils. Table 1 shows the grain-size fractions, moisture content, and volume weight of these soils.

The application of load on the lever was not instantaneous but by stages, which usually permitted a ten-minute interval after which a further load of 0.4 to 0.5 kilogram per square centimeter was added. Exceptions to this procedure were rare and were made only as a result of some special circumstance in the experiment. Table 2 lists the results of the determinations of adfreezing strength, accompanied by a detailed description of the course of each experiment. [Note: The last three experiments listed in Table 2 were not numbered. Ed.]

These results of the tests for adfreezing strength between ground and wood or concrete made clear that the post began to move upward in virtually every case, immediately after the first load was applied. The adfreezing strength in such a case must, it would appear, be less than when the full load was applied in a brief period of time. It follows, then, that failure to make sufficient provision for plastic deformations in frozen ground may result in serious errors in computation.

It is of interest to note that a repetition of the experiments with some of the posts (#15 and others) showed adfreezing strengths of the same order the second time as the first, even though they had been removed from their original place during the first tests. However, the second test with post #18 caused the soil to give way. In that case, the adfreezing strength of ground to concrete exceeded the tensile strength of frozen ground (Figs. 6 and 7).

If we assemble the foregoing data on adfreezing strengths into a single table, assuming adfreezing strength to be equivalent to load at maximum deflectometer reading, we obtain the results shown in Table 3. [Note: Data in Table 3 do not conform exactly with Tables 1 and 2; in some instances the numbers were rounded out. Ed.]

An over-all analysis of the data in Table 3 permits the following conclusions. [Note: Some of the figures were rounded out in the original Russian while others were not. Ed.]

1. The adfreezing strength of wood to sand, when the

Table 1

GRAIN-SIZE FRACTIONS, MOISTURE CONTENT, AND VOLUME WEIGHT OF TESTED GROUNDS

Material and post number	Grain-size fractions, %							% moisture		Volume weight	
	0.5-0.25 mm.	0.25-0.05 mm.	0.05-0.01 mm.	0.01 mm.	0.01-0.005 mm.	0.005-0.001 mm.	0.001 mm.	by weight	by volume	of mineral fraction	of ground sample
Wood											
8	62.50	36.50	0.25	0.75	----	---	---	23.5	37.1	1.56	1.95
10	41.50	54.25	3.50	0.75	----	---	---	25.3	40.1	1.58	1.98
12	33.75	62.50	2.25	1.50	----	---	---	32.5	42.9	1.33	1.75
20	51.00	43.50	0.75	4.75	----	---	---	21.0	35.5	1.68	2.05
22	40.75	57.25	1.25	0.75	----	---	---	22.5	37.2	1.62	1.99
7	1.50	22.00	44.00	32.50	26.00	0.75	5.75	84.6	67.7	0.74	1.36
9	1.75	22.25	42.00	34.00	31.00	0.80	2.20	59.5	53.4	0.98	1.40
11	0.50	13.00	34.75	51.75	41.50	2.00	8.25	64.3	58.8	0.91	1.39
19	0.75	32.00	28.25	39.00	34.75	2.75	1.50	57.9	55.3	0.97	1.52
21	3.75	25.25	35.00	36.00	29.50	0.50	6.00	142.3	83.5	0.65	1.58
Concrete											
14	64.50	33.50	0.50	1.50	----	---	---	Not determined.			
16	54.00	46.50	0.10	2.40	----	---	---	23.2	38.9	1.68	2.13
18	63.00	35.00	1.50	0.50	----	---	---	21.5	30.8	1.45	1.76
1	0.75	25.25	33.25	34.75	23.25	5.50	6.00	68.6	62.6	0.93	1.55
3	0.75	27.50	38.75	33.00	27.50	2.25	3.25	42.8	54.8	1.29	1.84
5	0.50	19.00	39.00	41.50	36.00	3.00	2.50	70.8	55.6	0.86	1.36
13	1.75	20.50	30.00	47.75	39.00	3.13	5.62	59.8	58.2	0.97	1.55
15	2.00	17.25	37.00	43.75	35.50	2.25	6.00	53.0	54.8	1.04	1.58
17	1.25	29.50	33.75	35.50	27.25	4.00	4.25	64.0	61.7	0.98	1.59
25	3.00	26.25	33.75	37.00	28.30	8.10	0.60	63.4	48.7	0.70	1.26



Fig. 3. View of setup for test of adfreezing strength (Igarka, 1938).

moisture content of the latter is from 21 to 32.5% by weight, or 35 to 42% by volume, and its temperature lies between -0.9° and -8.9°C . will range from 5 to 10 kg./cm.^2 (Fig. 8).

2. When silt-dust ground contains 57.9 to 112.3%

moisture by weight or 53.4 to 83.5% by volume, and its temperature lies between 0° and -10.8°C ., it will ad-freeze to wood with a strength of 1.5 to 4 kg./cm.^2 (Fig. 9). It follows that the adfreezing strength of wood to sand is larger than that of wood to silt-dust ground

Table 2

TEST DATA OF ADFREEZING STRENGTH OF WOOD AND CONCRETE TO GROUND UNDER NATURAL CONDITIONS ON EXPERIMENTAL PLOT OF IGARKA PERMAFROST STATION IN 1938

Experiment number and date	Types of post and ground	Adfreezing area, cm. ²	Ground temperature, °C.						Force of extraction, kg./cm. ²	Deflectometer reading in 0.01 mm.	Time of load action, min.	Remarks
			At ground surface		At 0.25 m.		At 0.5 m.					
			Initial	Final	Initial	Final	Initial	Final				
8 7/III	Wood	2500	-1.2°	-0.9°	-4.8°	-4.7°	-5.2°	-5.1°	1.03	1	10	
	—								1.54	3	10	
	Sand								1.98	7	10	
									2.41	17	10	
									2.88	34	10	
									3.39	53	10	
									3.90	84	10	
									4.40	136	10	
10 26/III	Wood	1630	-8.9°	-8.8°	-8.5°	-8.5°	-5.4°	-5.5°	5.01	704	5	The pole was pulled out
	—								2.12	0	10	
	Sand								3.07	13	10	
									4.03	37	10	
									4.92	53	10	
									5.88	86	10	
									7.03	168	10	
									8.17	261	10	
12 4/IV	Wood	2195	-0.4°	-0.4°	-4.0°	-4.3°	-3.2°	-3.4°	8.99	394	10	The pole was pulled out
	—								9.86	457	5	
	Sand								1.09	3	10	
									1.60	8	5	
									2.10	22	10	
									2.69	46	10	
									3.29	84	10	
									3.74	121	10	
20 5/IV	Wood	2500	-0.6°	-0.4°	-4.9°	-4.8°	-4.4°	-4.7°	4.21	189	10	The pole was pulled out
	—								4.65	250	10	
	Sand								5.15	351	10	
									5.65	551	10	
									6.30	664	10	
									0.59	6	10	
									1.52	19	10	
									2.06	34	10	
22 7/IV	Wood	1820	-0.4°	-0.2°	-2.2°	-2.6°	-2.8°	-3.5°	2.68	69	10	The pole was pulled out
	—								3.22	123	10	
	Sand								3.84	202	10	
									4.39	327	10	
									5.00	523	10	
									5.76	723	10	
									0.63	2	10	
									1.85	12	10	
7 28/III	Wood	3212	-5.6°	-5.8°	-6.8°	-6.5°	-5.2°	-5.1°	2.70	30	10	The pole was pulled out
	—								3.54	86	10	
	Dust-silt ground								4.44	178	8	
									1.26	3	10	
									1.67	4	10	
									2.05	7	10	
									2.47	11	10	
									2.88	28	10	
9 29/III	Wood	3575	-10.8°	-10.3°	-4.1°	-3.5°	-4.1°	-3.5°	3.24	52	10	The pole was pulled out
	—								3.58	60	10	
	Dust-silt ground								0.97	3	10	
									1.36	6	10	
									1.74	16	10	
									2.18	31	10	
									2.58	54	10	
									3.02	97	10	
									3.45	189	10	The pole was pulled out
									3.88	310	10	

Table 2 (Cont'd.)

Experiment number and date	Types of post and ground	Adfreezing area, cm. ²	Ground temperature, °C.						Force of extraction, kg./cm. ²	Deflectometer reading in 0.01 mm.	Time of load action, min.	Remarks	
			At ground surface		At 0.25 m.		At 0.5 m.						
			Initial	Final	Initial	Final	Initial	Final					
11 5/IV	Wood	330	-1.0°	-1.2°	-2.2°	-2.3°	-2.8°	-2.8°	0.54	6	10	The pole was pulled out	
	—								1.07	13	10		
	Dust-silt ground								1.65	20	10		
	—								2.14	48	10		
	—								2.97	127	10		
19 7/IV	Wood	4920	-1.0°	-1.2°	-1.9°	-2.3°	-4.2°	-4.2°	3.30	---	--		The pole was pulled out
	—								0.63	4	10		
	Dust-silt ground								0.93	29	10		
	—								1.25	213	10		
	—								1.52	---	--		
21 7/IV	Wood	3600	-0.0°	-0.2°	-3.0°	-3.2°	-3.5°	-3.4°	0.17	3	10		
	—								0.57	9	10		
	Dust-silt ground								0.88	14	10		
	—								1.19	23	10		
	—								1.43	47	10		
	—								1.66	63	10		
	—								1.89	105	10		
	—								2.14	146	10		
	—								2.41	234	10		
	—								2.68	341	10		
16 9/IV	Concrete	3600	-0.7°	-0.7°	-0.7°	-2.5°	-2.5°	-2.8°	2.92	801	10	The pole was pulled out	
	—								0.26	2	10		
	Sand								0.78	4	10		
	—								1.19	12	10		
	—								1.64	35	10		
	—								2.13	74	10		
	—								2.36	138	10		
	—								2.66	217	10		
	—								2.98	359	10		
	—								3.33	536	10		
18 2/IV	Concrete	3980	-1.4°	-2.0°	-5.1°	-4.8°	-5.7°	-5.7°	3.67	803	10	The pole was pulled out	
	—								4.08	1410	10		
	Sand								0.83	1	10		
	—								1.17	1	10		
	—								1.51	3	10		
	—								1.90	11	10		
	—								2.28	25	10		
	—								2.60	52	10		
	—								3.02	88	10		
	—								3.46	143	10		
18 29/IV	Concrete	3980	-6.8°	-6.4°	-5.3°	-5.7°	-5.4°	-5.4°	3.91	226	10	The pole was not pulled out	
	—								4.33	358	10		
	Sand								4.72	468	10		
	—								5.15	659	10		
	—								5.55	693	10		
	—								1.44	7	10		
	—								1.82	18	10		
	—								2.13	33	10		
	—								2.53	56	10		
	—								2.88	82	10		
	—								3.17	110	10		
	—								3.51	144	10		
	—								3.88	177	10		
	—								4.19	229	10		
	—								4.57	285	10		
	—								4.95	353	10		
	—								5.45	491	10		
	—								6.00	667	10		
	—								6.56	998	10		
	—								7.29	1503	10		
	—								7.71	2202	10		
—	—	—	—	—	—	—	—	—	—	—	With a general extracting load of 30,670 kg., a portion of the ground ad-frozen to the pole was torn from the general mass (Figs. 6 & 7)		

With a general extracting load of 30,670 kg., a portion of the ground ad-frozen to the pole was torn from the general mass (Figs. 6 & 7)

Table 2 (Cont'd.)

Experiment number and date	Types of post and ground	Adfreezing area, cm. ²	Ground temperature, °C.						Force of extraction, kg./cm. ²	Deflectometer reading in 0.01 mm.	Time of load action, min.	Remarks
			At ground surface		At 0.25 m.		At 0.5 m.					
			Initial	Final	Initial	Final	Initial	Final				
1 15/V	Concrete	4330	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	0.48	13	10	The pole was pulled out
	—								0.68	26	10	
	Dust-silt ground								0.82	45	10	
									0.98	81	10	
									1.38	153	10	
									1.73	702	10	
3 15/V	Concrete	4360	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	2.10	---	--	The pole was pulled out
	—								1.80	126	10	
	Dust-silt ground								2.20	388	10	
5 14/V	Concrete	5490	-0.1°	-0.1°	-0.7°	-0.7°	-0.5°	-0.5°	0.82	10	10	The pole was pulled out
	—								1.03	29	10	
	Dust-silt ground								1.23	117	10	
									1.40	147	10	
									1.56	282	10	
									1.72	773	10	
13 26/IV	Concrete	4629	-7.8°	-5.1°	-2.4°	-2.5°	-1.5°	-1.5°	1.87	863	10	The pole was pulled out
	—								2.06	---	--	
	Dust-silt ground								1.92	12	40	
									2.76	43	40	
									3.52	65	10	
									3.90	142	10	
15 10/IV	Concrete	4450	-0.0°	-0.1°	-1.3°	-1.5°	-1.3°	-2.2°	4.44	185	10	Pole was not pulled out due to weakness of levers
	—								4.91	282	10	
	Dust-silt ground								5.28	456	10	
									5.73	820	10	
									0.29	3	5	
									0.63	6	10	
15/IV	Concrete	4450	-0.6°	-0.2°	-1.8°	-2.5°	-2.2°	-2.2°	0.96	9	10	Pole was not pulled out due to technical reasons
	—								1.31	14	10	
	Dust-silt ground								1.59	23	10	
									1.89	38	10	
									2.14	66	10	
									2.42	98	10	
17/IV 28/IV	Concrete	4200	-7.8°	-7.8°	-3.4°	-3.8°	-2.9°	-2.9°	2.78	161	10	Second test took place 17 days after the first
	—								3.06	246	10	
	Dust-silt ground								3.32	376	10	
									3.59	590	10	
									3.88	915	10	
									1.93	21	10	
17/IV 28/IV	Concrete	4200	-7.8°	-7.8°	-3.4°	-3.8°	-2.9°	-2.9°	2.34	43	10	Pole was not pulled out due to weakness of lever
	—								2.58	75	10	
	Dust-silt ground								3.05	123	10	
									3.41	192	10	
									3.69	279	10	
									4.00	417	10	
17/IV 28/IV	Concrete	4200	-7.8°	-7.8°	-3.4°	-3.8°	-2.9°	-2.9°	4.43	670	10	Pole was not pulled out due to weakness of lever
	—								4.83	925	10	
	Dust-silt ground								5.74	2065	10	
									1.42	9	10	
									1.74	13	10	
									2.26	19	10	
17/IV 28/IV	Concrete	4200	-7.8°	-7.8°	-3.4°	-3.8°	-2.9°	-2.9°	2.58	24	10	Pole was not pulled out due to weakness of lever
	—								2.96	32	10	
	Dust-silt ground								3.35	47	10	
									3.74	61	10	
									4.06	80	10	

Table 2 (Cont'd.)

Experiment number and date	Types of post and ground	Adfreezing area, cm. ²	Ground temperature, °C.						Force of extraction, kg./cm. ²	Deflectometer reading in 0.01 mm.	Time of load action, min.	Remarks
			At ground surface		At 0.25 m.		At 0.5 m.					
			Initial	Final	Initial	Final	Initial	Final				
17/IV 28/IV	Concrete	3330	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	-0.2°	4.40	103	10	Pole was not pulled out due to weakness of lever
	Dust-silt ground								4.68	133	10	
									5.29	193	10	
									5.81	272	10	
									6.44	432	10	
28/IV	Concrete								7.25	952	10	Pole was pulled out; it was cylindrical in form
	Dust-silt ground								1.51	30	10	
									1.79	293	10	

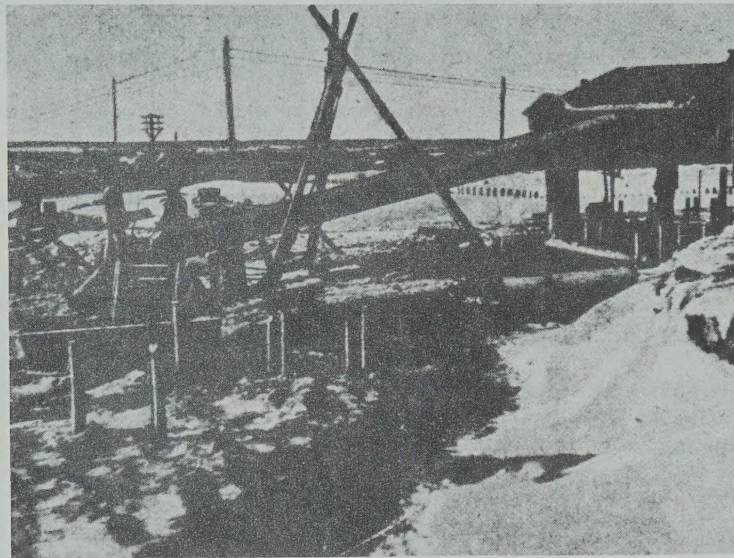


Fig. 4. View of setup for test of adfreezing strength with new lever arrangement (Igarka, 1938).

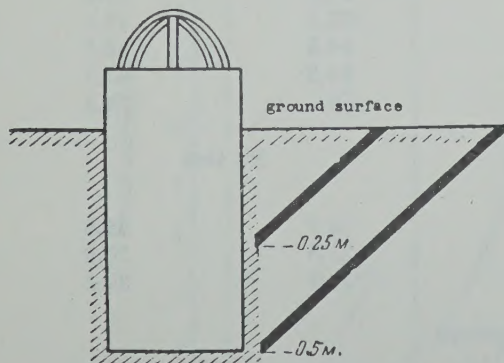


Fig. 5. Arrangement of thermometers during determination of adfreezing strength.

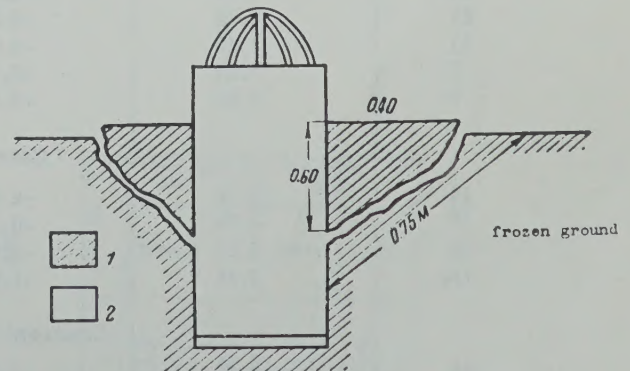


Fig. 6. Breakaway of concrete post #18 with adjacent soil from frozen ground mass (1. ground; 2. concrete post).

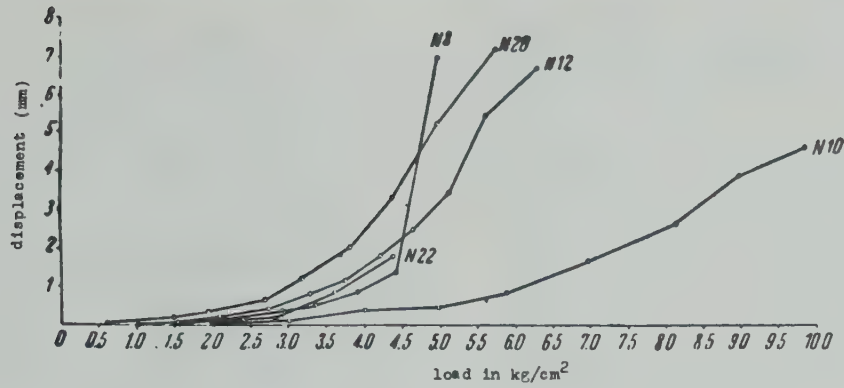


Fig. 7. Concrete post #18 with chunk of adjacent soil that tore away from frozen ground mass (Igarka, 1938).

Table 3

COMPOSITE TABLE OF TEST DATA ON ADFREEZING STRENGTH UNDER NATURAL CONDITIONS

Post #	Adfreezing strength, kg./cm. ²	Temperature during tests, °C.		% moisture	
		From	To	By weight	By volume
		Wood to sand			
22	4.40	-0.2	-3.5	22.5	37.2
8	5.00	-0.9	-5.2	23.5	37.1
20	5.76	-0.4	-4.9	21.0	35.5
12	6.30	-0.4	-4.3	32.5	42.9
10	9.86	-5.4	-8.9	25.3	40.2
		Wood to silt-dust ground			
19	1.52	-1.0	-4.2	57.9	55.3
21	3.22	0.0	-3.5	112.3	83.5
11	3.30	-1.0	-2.8	64.3	58.8
7	3.58	-5.1	-6.8	84.6	67.7
9	3.88	-3.5	-10.8	59.5	53.4
		Concrete to sand		No test	
14	3.76	-4.0	-7.7		
16	4.08	-0.7	-2.8	23.2	38.9
18	5.55	-1.4	-5.7	21.5	30.8
18a	7.71	-5.3	-6.8	21.5	30.8
		Concrete to silt-dust ground			
25	1.79	0.0	-0.2	63.4	48.7
1	2.10	0.0	-0.2	68.6	62.6
3	2.20	0.0	-0.2	42.8	54.8
5	2.06	-0.1	-0.7	70.8	55.6
15	3.88	0.0	-2.2	53.0	54.8
13	5.73	-1.5	-7.8	59.8	58.2
15	5.74	-0.2	-2.5	53.0	54.8
17	7.25	-2.9	-7.8	64.0	61.7



Pole No.	Temperature in C.		Moisture in %	
	From	To	Grav.	Volum.
8	-0.9	-5.2	23.5	31.1
10	-5.4	-9.9	25.3	40.2
12	-0.4	-4.3	32.5	42.9
20	-0.4	-4.9	21.0	35.5
22	-0.2	-3.5	22.5	37.2

Fig. 8. Relation of motion of wooden posts to load during withdrawal from frozen sand at various temperatures and degrees of ground moisture.

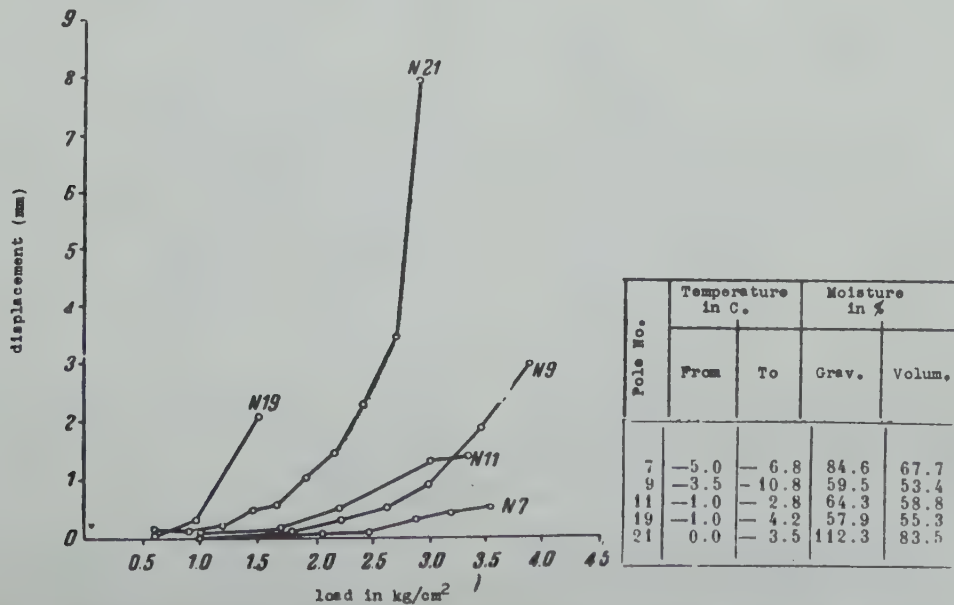
under approximately identical temperatures, regardless of the fact that the silt-dust ground contains more ice.

3. The adfreezing strength of concrete to sand with a moisture content of 21.5 to 23.2% by weight, or 30.8 to 38.9% by volume, and at temperatures of -0.7° to -6.8°C . varies from 4 to 8 kg./cm^2 (Fig. 10).

4. The same holds for the adfreezing of concrete to silt-dust soil. When the ground moisture runs 53 to

70.8% by weight, or 48.7 to 62.6% by volume, and its temperature range is 0° to -7.8°C ., adfreezing strength will vary between 1.8 and 7.25 kg./cm^2 (Fig. 11).

Thus, adfreezing strengths are virtually the same for concrete to sand and concrete to silt-dust ground when temperatures are approximately the same, but the ice content is about 50% higher in the second case.



Pole No.	Temperature in C.		Moisture in %	
	From	To	Grav.	Volum.
7	-5.0	-6.8	84.6	67.7
9	-3.5	-10.8	59.5	53.4
11	-1.0	-2.8	64.3	58.8
19	-1.0	-4.2	57.9	55.3
21	0.0	-3.5	112.3	83.5

Fig. 9. Relation of motion of wooden posts to load during withdrawal from frozen silt-dust soil at various temperatures and degrees of ground moisture.

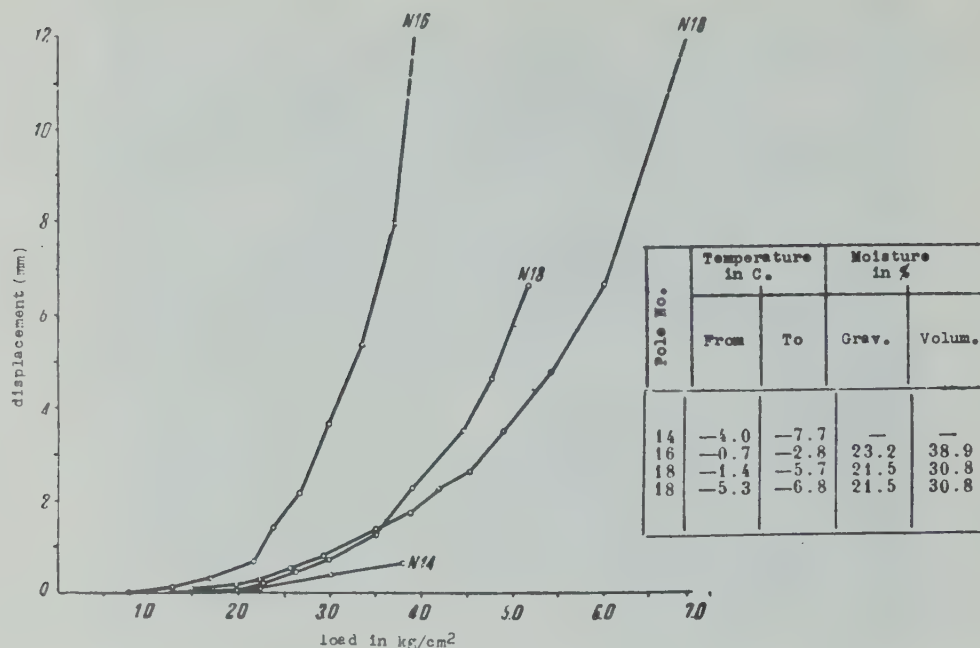


Fig. 10. Relation of motion of concrete posts to load during withdrawal from frozen sand at various temperatures and degrees of ground moisture.

Therefore, if the moisture content were identical, sandy soil would show a greater adfreezing strength.

If readings for posts of various materials were compared, it will be found that, all other things being equal, both wood to sand and concrete to sand show approximately equal adfreezing strengths. If, however, analogous comparisons were made for silt-dust ground, concrete posts will show greater adfreezing strengths than wooden.

Finally, let us compare the results of the tests made at the Igarka Permafrost Station with those made at the L.I.L.K.S. Soil Mechanics Laboratory. In answer to queries arising from the fact that the laboratory tests employed waterlogged wooden posts, it may be said that while the wooden posts used at Igarka were air-dried, it is certain that at least their outer layers must have become saturated with water during the first six weeks or two months in the ground, for there were regular rains during that period that were able both to soak the ground and run down the entire length of the posts. There is, therefore, adequate basis for comparison with the laboratory tests.

I. S. Vologdina's article, "Sily smerzaniia merzlykh gruntov s derevom i betonom" (Adfreezing Strength of Frozen Soils to Wood and Concrete),² shows, on pp. 53-56, that the adfreezing strength of moist wood to clayey sand was much greater in the laboratory than under our conditions.

Thus, with an average temperature of -2.7°C . and a moisture content of 10.1%, the adfreezing strength under laboratory conditions was 11.2 kg./cm.^2 , while at -5.6°C .

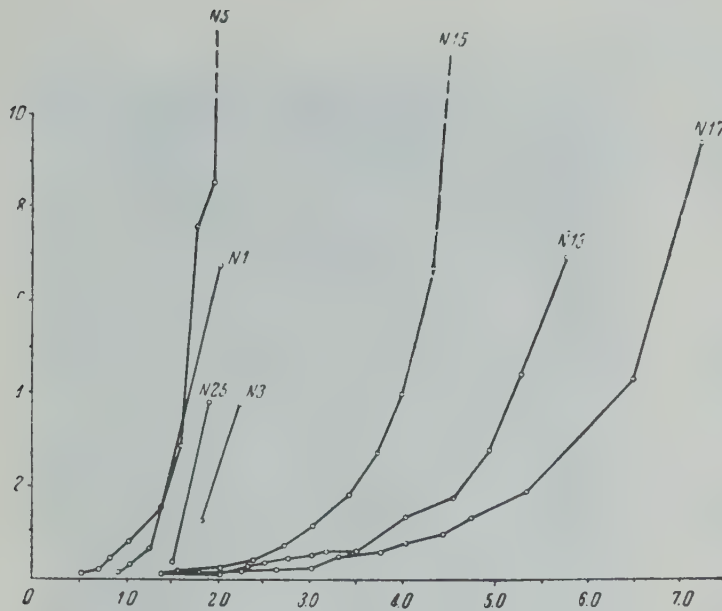
and 12.9% ground moisture, the adfreezing strength was 20.8 kg./cm.^2 . Our work showed, however, that the adfreezing strength of sand to wood at -0.2° to -5.2°C . and with 21 to 32.5% moisture by weight did not exceed 6.3 kg./cm.^2 , while even at -5.4° to -8.9°C . and 25.3% moisture, the adfreezing strength was only 10 kg./cm.^2 . As may be seen, the difference is considerable. We arrive at the same conclusion, if similar comparisons be made between field and laboratory results for adfreezing strength between wood and silt-dust ground.

For the relationship between concrete and the ground, laboratory research arrived at the following magnitudes, employing silt-dust ground. At a temperature of -1° to -1.9°C ., and a moisture content of between 44 and 45.4%, the adfreezing strength to concrete ranged from 8.5 to 10.5 kg./cm.^2 . In our experiments, however, with lower temperatures and higher ground moisture (posts 13, 15, 17), adfreezing strengths did not exceed 6 kg./cm.^2 . True, these posts were not extracted all the way, but the type of deformation they underwent in the process showed how close the readings obtained were to the possible maximum.

Figures 8, 9, 10, and 11, showing the relation of deformation of the posts to load at various temperatures and degrees of ground moisture, demonstrate the uniformity of those curves. At first, there is a very gradual rise, then a regular increase in steepness, and finally an almost vertical ascent.

It is clear beyond question that the factor determining the nature of those curves was, under the conditions we faced, the temperature of the ground. As it declined, the

2. Laboratornye issledovaniia mekhanicheskikh svoistv merzlykh gruntov (Laboratory Studies of the Mechanical Properties of Frozen Ground), 1st Papers, Academy of Sciences, 1936.



Pole No.	Temperature in C.		Moisture in %	
	From	To	Grav.	Volum.
1	0.0	-0.2	68.6	62.6
3	0.0	-0.2	42.8	54.8
5	-0.1	-0.7	70.8	55.6
13	-1.5	-7.8	59.8	58.2
15	-0.2	-2.5	53.0	54.8
17	-2.9	-7.8	64.0	61.7
25	0.0	-0.2	63.4	48.7

Fig. 11. Relation of motion of concrete posts to load during withdrawal from frozen silt-dust soil at various temperatures and degrees of ground moisture.

curve tended ever farther away from the ordinate, becoming flatter and flatter. This situation, long known from laboratory experiments, is therefore supported by our experiments. That is particularly clear from the graph (Fig. 11) for the adfreezing of concrete and silt-dust ground. The left side of the graph carries a number of curves for the higher temperatures, close to 0°C ., while the right side pertains to the lower, down to -7.8°C .

The exceptions to this general rule reflect higher ice content, a factor that influences adfreezing strength as much as temperature.

Finally, it should be noted that, in comparing the results of the field experiments with the corresponding data obtained in the Soil Mechanics Laboratory, the determination of adfreezing strength in the first instance was conducted by a process of extracting posts, and in the second, by driving posts into the ground.

The data presented in the present article will be rendered more precise by further experiments to be conducted in 1939, also in the natural environment at

Igarka. They will test adfreezing strength both by extracting and driving posts.

This many-sided approach to experiments for the determination of adfreezing strength will make it possible to establish which method is most accurate.

To permit an even closer comparison between the adfreezing strengths already determined in nature and those arrived at in the laboratory, it has been decided to make laboratory tests of the same soils which were tested in nature. Moreover, the samples are to be delivered to the laboratory in the same state of moisture and density as they had when tested under field conditions. After these experiments have been conducted, we will be able to compare laboratory and field findings more intelligently.

II. Experiments to Determine the Shear Strength of Frozen Ground in Nature

At the beginning of 1938, the Igarka Permafrost Station also conducted tests to determine the shear strength of frozen ground. It should be noted that while the study of adfreezing strength has some history, research into the shear strength of frozen ground has just begun. The only work previously conducted in this field was done at the L.I.I.K.S. Soil Mechanics Laboratory, and described in M. L. Sheikov's article, "Soprotivlenie sdvigu merzlykh gruntov" (The Shear Strength of Frozen Ground).

Our method differed from that used at the Laboratory in the following manner: (1) the shear surfaces in our experiments were much larger (200 to 800 sq. cm.); (2) the soil was tested as it existed in nature; (3) there was a temperature differential of 5.6°C . in our samples between their interior and exterior; and (4) the load applied at the lever was gradually increased. The importance of this last factor is particularly great, for researches in recent years have demonstrated that the readings obtained in tests of this general sort depend

largely upon the rate of application of load.

The experiments were conducted as follows. A hole 1.5 to 2 meters deep was dug on the testing ground of the station in such a manner that some of the frozen silt-dust soil was permitted to project from the walls of the hole. There were two types of projection: some had one and others had two shear surfaces (Figs. 12, 13, and 14).

Ground temperatures were measured by means of retarded psychrometric thermometers with scales marked to 0.2 of a degree centigrade. The thermometers were installed directly into and laid on the surface of the shear plane. As the thermometers interfered with the shear surfaces, the method employed was to cut several projections simultaneously, using some for temperature purposes while the others were subjected to shear tests. Since both groups of projections were made at the same time and in identical manner, there is no reason to postulate any difference in temperature between them. Figures 12 and 13 show how the thermometers were installed.

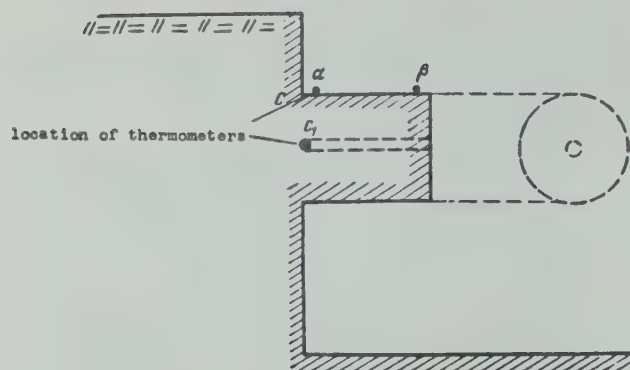


Fig. 12. Projection cut in frozen ground to provide single shear plane.

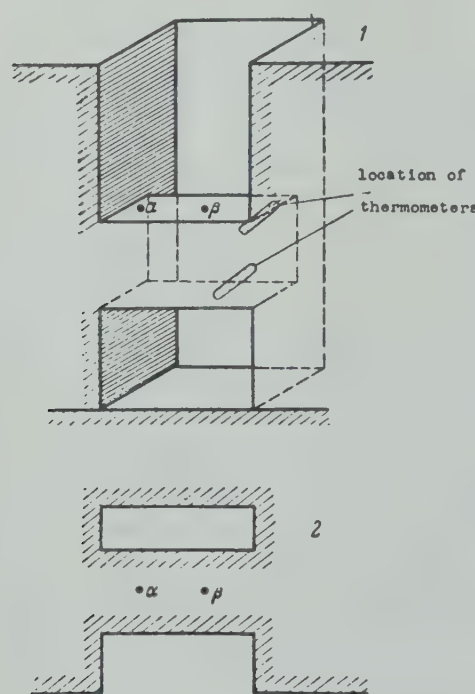


Fig. 13. Projection cut in frozen ground to provide two shear planes (1. front view; 2. top view).

A lever was used to apply shearing force, as shown on Figure 15. A bent piece of boiler iron would be placed beneath a projection with a single shear surface, and a cable was then passed beneath the iron. To prevent the projection from breaking off, the cable was placed at the very base of the projection, adjoining the wall. If the sample had two shear surfaces, a wooden block would be placed beneath it. The dimensions of the top of the block would be identical to those of the bottom of the projection. A steel cable would then be passed beneath the block in such manner that the load would be applied along the shearing plane (Fig. 16).

Pitch or grease was liberally applied to the projections so as to avoid evaporation from them, as shown in Figure 14.

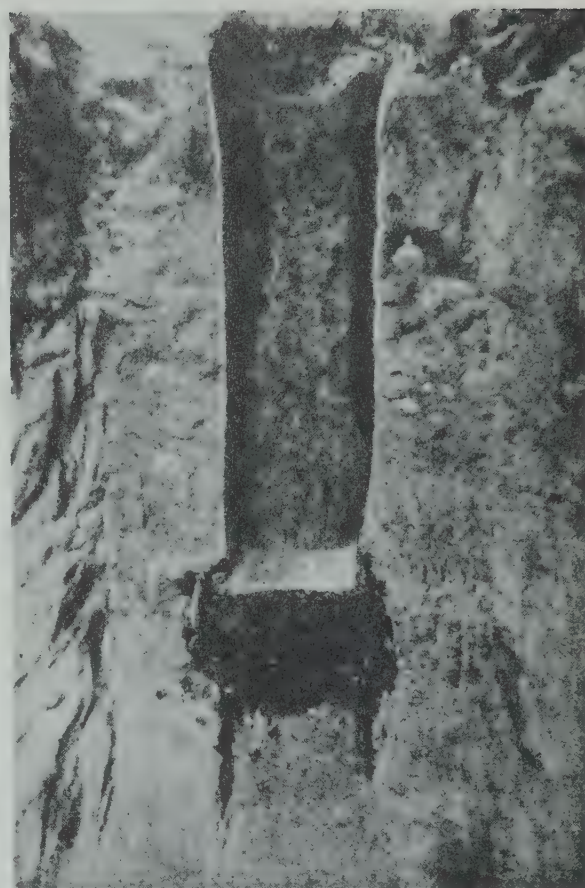


Fig. 14. Projection cut in frozen ground to provide two shear planes; shows greasing to preserve ice evaporation (Igarka, 1938).

L.I.I.K.S. deflectometers were used to measure the deformations caused by shear. They were installed at two points, α and β (Fig. 12), in the samples with a single plane of shear, while in the samples with two planes they were placed on top, in the middle, and at the plane of application of load. The measurement of deformation at β in both cases served the purpose of determining whether the sample had been fractured, although every possible precaution was taken to avoid this.

After the experiments, samples were taken from the ground at the point of shear to determine moisture content, volume weight, and other properties of the soil.

It should be noted at the outset that the tests performed upon the samples with only a single plane of shear were not successful, because the projections broke off in every single case despite the most painstaking efforts to avoid this. For this reason we shall not give detailed attention to the readings in these cases. Of eight such experiments we have chosen to describe two by way of example (tests numbered 7 and 8). Table 4 shows the mechanical composition of the ground subjected to test.

Table 4

Test #	Percentage of grain sizes						
	0.5-0.25 mm.	0.25-0.05 mm.	0.05-0.01 mm.	< 0.01 mm.	0.01-0.005 mm.	0.005-0.001 mm.	< 0.001 mm.
7	0.25	20.75	43.00	36.00	30.25	3.25	2.50
8	2.00	19.75	44.50	33.75	26.25	5.75	1.75

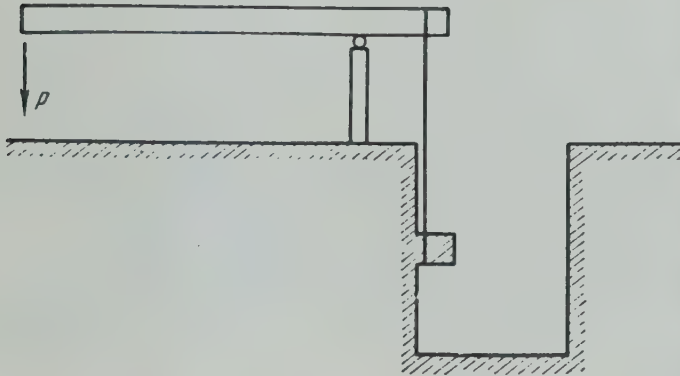


Fig. 15. Scheme of apparatus for the determination of shear strength.

The conditions and results of the tests were as follows. (From this point on, we use the following equivalents: e_B = moisture content by weight; e_C = moisture content by volume; δ = volume weight of mineral fraction; and γ = volume weight of natural ground sample.) [F = area of shear surface; C and C_1 = location of thermometers. Ed.]

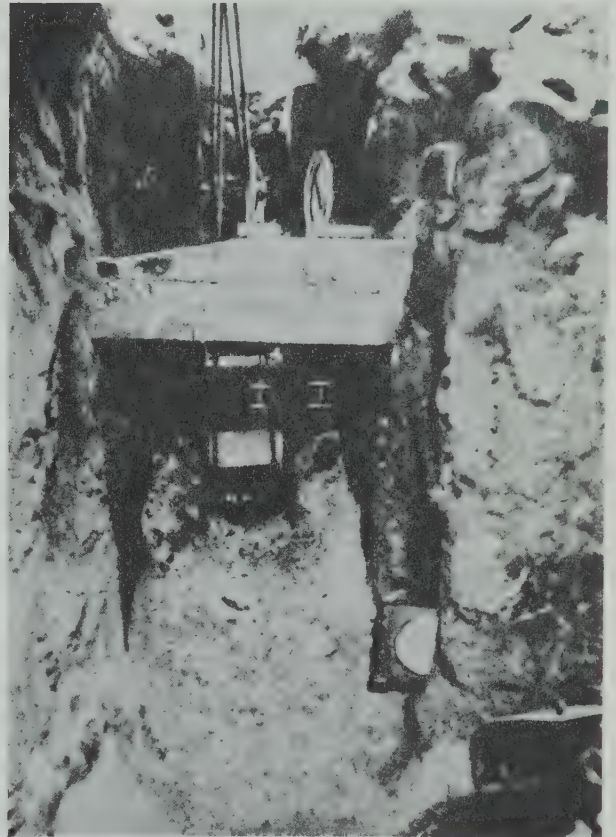


Fig. 16. Shear test setup of frozen ground projection with two shear planes (Igarka, 1938).

Test 7

$$F = 400 \text{ cm.}^2$$

March 16, 1938

Temperature of projection subjected to shear:

At point C

At point C_1

At beginning of test

-11.7°C.

-12.2°C.

At end of test

-10.7

-11.0

$$e_B = 25\%; \quad e_C = 37.7\%;$$

$$\delta = 1.56; \quad \gamma = 1.96$$

The ground was not plastic at all.

Load, kg./cm. ²	1.35	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Deformation of projection in } α	0	0	0	1	1	.1	2	9	38
0.01 mm. at points } β	0	0	3	6	15	51	95	224	448

The projection broke off.

Test 8

$$F = 400 \text{ cm.}^2$$

March 19, 1938

Temperature of projection subjected to shear:

At beginning of experiment

At end of experiment

At point C

-18.6°C.

-18.3

At point C₁

-16.1°C.

-17.4

$$e_B = 28.8\%;$$

$$e_C = 40.4\%;$$

$$\delta = 1.4;$$

$$\gamma = 1.8$$

The Atterberg plasticity index was 2.3.

Load, kg./cm. ²	1.27	2.0	3.0	4.0	5.0	6.0	7.0
Deformation of projection in } α	0	2	2	4	13	31	69
0.01 mm. at points } β	0	0	0	7	29	141	355

The projection broke off.

The two samples we have just cited offer ample proof of our view that the experiments for shear based on a single shear plane were unsuccessful.

Let us now proceed to examine the experiments with projections having two shear planes. In this connection we worked with samples having shear surfaces of 200, 400, and 800 sq. cm. The corresponding widths of the planes were 10, 14, and 20 cm., and their lengths varied from 15 to 20 cm.

Shear strengths were determined only for silt-dust soils. Analysis of the samples necessitates dividing them into two groups. The silt fraction (0.25 to 0.01 mm.) predominated in the first over the dust fraction (0.01 to 0.005 mm.). In the second, the fractions were equal or the dust fraction predominated. Table 5 presents the average mechanical composition of these types of soils.

Table 5

MECHANICAL COMPOSITION OF TWO TYPES OF SOIL TESTED

Percentage of grain sizes							Remarks
0.5-0.25 mm.	0.25-0.05 mm.	0.05-0.01 mm.	< 0.01 mm.	0.01-0.005 mm.	0.005-0.001 mm.	< 0.001 mm.	
		Type I (Tests 9, 10, 11, 12, 13, 16, and 19)					Average of 7 Maximum of 7 Minimum of 7
1.32	20.25	41.00	37.55	32.20	2.23	4.14	
3.50	28.00	44.50	42.00	36.17	3.75	5.00	
0.37	13.00	36.50	31.25	25.00	0.94	2.82	
		Type II (Tests 5, 14, 15, 17, 18, 20, 21, and 22)					Average of 8 Maximum of 8 Minimum of 8
0.60	7.69	31.30	60.55	54.00	1.84	4.77	
1.25	13.00	39.50	78.40	68.95	6.25	7.00	
0.00	3.75	13.60	49.50	42.75	0.50	0.75	

The time permitted to elapse between increases in load upon the lever differed from one sample to the next. We now proceed to describe the various tests of projections having two planes of shear.

Test 9

$$F = 800 \text{ cm.}^2$$

March 20, 1938

Ground temperature of projection:

At beginning of test

After 160 minutes

After 205 minutes

At surface

-15.4°C.

-11.8

- 9.6

Inside

-17.4°C.

-12.1

- 9.8

$$e_B = 30.4\%;$$

$$e_C = 43.8\%;$$

$$\delta = 1.44;$$

$$\gamma = 1.88$$

The ground sample had no Atterberg plasticity (it was not ductile).

Test 9 (Contd.)

Load, kg./cm. ²	4	5	6	7	8	9	10	11	12	13	14	15	16
Deformation of the sample } β	0	0	1	1	1	1	3	4	19	73	154	298	619
in .01 mm. at points } α	6	2	4	6	8	11	20	25	53	101	264	413	785

Complete shearing of the sample began. After the load reached 14 kg./cm.² a small crack appeared in the middle of the sample. Load was applied every 15 minutes, and readings of the deflectometer were made at the same interval.

Test 10

F = 800 cm.²

March 26, 1938

Ground temperature of projection:

At surface
-2.0°C.Inside
-3.6°C. $e_B = 25\%$; $e_C = 38.2\%$; $\delta = 1.52$; $\gamma = 1.9$

Atterberg plasticity index was 2.15.

Load, kg./cm. ²	2.7	3.7	4.7	5.7	6.7
Deformation of sample in } β	14	81	327	659	1389
0.01 mm. at points } α	70	195	483	808	2308

Complete shearing off of the sample set in. Application of load and reading of the deflectometer took place every 10 minutes.

Test 11

F = 400 cm.²

April 3, 1938

Ground temperature of projection:

At surface

Inside

At beginning of test

-14.8°C.

-10.8°C.

At end of test

-13.8

-12.0

 $e_B = 26.7\%$; $e_C = 41.1\%$; $\delta = 1.15$; $\gamma = 1.95$

Atterberg plasticity index was 5.73.

Load, kg./cm. ²	2.43	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Deformation of sample in } β	0	0	0	1	2	3	12	14	15	38	56	98	144	300	432	612	876	995
0.01 mm. at points } α	3	7	12	17	20	20	37	52	70	106	154	227	338	514	721	1031	1446	1596

Complete shear of the sample began. A crack appeared in the sample at 11 kg./cm.² Load was applied and the deflectometer read every 15 minutes.

Test 12

F = 200 cm.²

April 4, 1938

Ground temperature of projection:

At surface

Inside

At beginning of test

-7.2°C.

-7.2°C.

At end of test

-6.8

-7.6

 $e_B = 26.7\%$; $e_C = 44.2\%$; $\delta = 1.65$; $\gamma = 2.10$

Atterberg plasticity index was 2.59.

Load, kg./cm. ²	2.9	4	5	6	7	8	9	10	11	12	13	14
Deformation of sample in } β	1	1	3	6	28	70	143	263	413	693	1333	2498
0.01 mm. at points } α	5	8	12	24	56	125	266	338	554	889	1604	2734

Load was applied and readings taken on the deflectometer every 10 minutes.

Test 15

 $F = 800 \text{ cm.}^2$

May 3, 1938

Ground temperature of projection:

At surface

Inside

During test

-3.7°C.

-4.3°C.

 $e_B = 38\%$; $e_C = 48.7\%$; $\delta = 1.28$; $\gamma = 1.77$

Atterberg plasticity index was 5.9.

Load, kg./cm. ²	2	3	4	5	6	7	8
Deformation of sample in } β	1	23	114	344	784	2082	2552
0.01 mm. at points } α	0	40	153	432	917	2039	3569

Load was applied and deflectometer readings taken every 10 minutes. The final reading was taken immediately after loading the lever.

Test 16

 $F = 800 \text{ cm.}^2$

April 4, 1938

Ground temperature of projection:

At surface

Inside

During test

-5.6°C.

-4.6°C.

 $e_B = 33\%$; $e_C = 42.8\%$; $\delta = 1.3$; $\gamma = 1.67$

Atterberg plasticity index was 1.31.

Load, kg./cm. ²	2	3	4	5	6	7	8
Deformation of sample in } β	9	53	138	364	831	1681	2651
0.01 mm. at points } α	11	60	192	534	1217	2367	3567

Application of load and readings on the deflectometer were taken every 10 minutes. The final reading was made 2-1/2 minutes after the final loading.

Test 17

 $F = 400 \text{ cm.}^2$

May 4, 1938

Ground temperature of projection:

At surface

Inside

During test

-2.8°C.

-4.8°C.

 $e_B = 46.5\%$; $e_C = 56.7\%$; $\delta = 1.22$; $\gamma = 1.79$

Atterberg plasticity index was 12.5.

Load, kg./cm. ²	2.5	3.5	4.5	5.5	6.5		
Deformation of sample in } β	18	122	417	1317	deflectometer destroyed		
0.01 mm. at points } α	54	252	752	2202	3832		

Load was applied, and the deflectometer read every 10 minutes. The final reading was within 3 minutes after application of load.

Test 18

 $F = 400 \text{ cm.}^2$

May 5, 1938

Ground temperature of projection:

At surface

Inside

During test

-3.3°C.

-4.0°C.

 $e_B = 68.5\%$; $e_C = 63.5\%$; $\delta = 0.91$; $\gamma = 1.55$

The ground was not plastic by the Atterberg test (the ground was not ductile).

Test 18 (Contd.)

Load, kg./cm. ²	1.7	2.7	3.7	4.7	5.7
Deformation of sample in } β	93	367	742	1862	3422
0.01 mm. at points } α	152	544	1064	2444	4184

Load was applied and the deflectometer read every 10 minutes. The final reading was made 2-1/2 minutes after application of load.

Test 20

F = 800 cm.²

April 7, 1938

Ground temperature of projection:

At surface

Inside

During test

-2.0°C.

-3.2°C.

$e_B = 59.3$ and 29.6% ; $e_C = 61.8$ and 42.6% ; $\delta = 1.05$ and 1.44 ; $\gamma = 1.66$ and 1.87

The ground was not plastic by the Atterberg test (it was not ductile).

Load, kg./cm. ²	1.25	2.25	3.25	4.25
Deformation of sample in } β	103	353	2013	3283
0.01 mm. at points } α	127	943	3429	----

Load was applied and the deflectometer read at 10-minute intervals. The last reading was made 2-1/2 minutes after application of load.

Test 21

F = 400 cm.²

May 7, 1938

Ground temperature of projection:

At surface

Inside

During test

-2.8°C.

-3.2°C.

$e_B = 41.8$ and 27.5% ; $e_C = 65.2$ and 49.5% ; $\delta = 1.56$ and 1.8 ; $\gamma = 2.33$ and 2.29

The Atterberg plasticity index was 2.59.

Load, kg./cm. ²	1.0	2.0	3.0
Deformation of sample in } β	148	1038	1438
0.01 mm. at points } α	296	1980	3080

Deflectometer readings were taken every 10 minutes. The final reading was taken 20 seconds after the application of load.

Test 22

F = 200 cm.²

May 7, 1938

Ground temperature of projection:

At surface

Inside

During test

-2.8°C.

-3.2°C.

$e_B = 36.5\%$; $e_C = 47.2\%$; $\delta = 1.3$; $\gamma = 1.78$

The Atterberg index of plasticity was 2.4.

Load, kg./cm. ²	1.83	2.33	2.83	3.33
Deformation of sample in } β	297	962	2952	3192
0.01 mm. at points } α	457	1257	3377	3657

Load was applied and deflectometer readings taken every 5 minutes. The final reading was taken immediately after the application of load.

Table 6

MAXIMUM LOADS AT POINT OF FINAL SHEAR OF SPECIMENS

Test #	Shear strength, kg./cm. ²	Temperature of sample during test, °C.		% moisture	
		From	To	By weight	By volume
Type I soils					
19	4.35	- 2.1	- 2.8	46.0	49.8
10	6.70	- 2.0	- 3.6	25.0	38.2
16	8.00	- 4.6	- 5.6	33.0	42.8
13	13.00	- 5.2	- 5.8	24.3	39.9
12	14.00	- 6.8	- 7.6	26.6	44.2
9	16.00	-11.8	-17.4	30.4	43.8
11	19.00	-10.8	-14.8	26.7	41.1
Type II soils					
21	3.00	- 2.8	- 3.2	41.8	65.2
	---	----	----	27.5	49.5
22	3.33	- 2.8	- 3.2	36.5	47.2
20	4.25	- 2.0	- 3.2	59.3	61.8
	---	----	----	29.6	42.6
18	5.70	- 3.3	- 4.0	68.5	63.5
14	6.00	- 5.2	- 5.8	28.0	29.1
17	7.50	- 2.8	- 4.8	46.5	56.7
15	8.00	- 3.7	- 4.3	38.0	48.7
5	15.24	-11.6	-12.6	30.1	46.5

Table 6 shows the maximum loads causing shearing off of the test samples.

In summation, it may be concluded that the shear strength of frozen ground increases with lower temperature. This corroborates the conclusion previously drawn from the experiments in the L.I.I.K.S. Laboratory.

The shear strength of silt-dust ground under natural conditions, with temperatures down to -10°C., does not exceed 14 or 15 kg./sq. cm. Variations from that temperature-strength ratio may possibly be explained in terms of varying ice content, location of ice wedges, and other factors. Thus, for example, samples 20, 21, and 22 showed mutually similar readings. However, if we compare them to sample 10, it appears that, although the temperatures were virtually identical, the last-named sample showed considerably greater strength. An even greater difference is shown if comparison be made with samples 13 and 14, which vary by more than 100% from the values for the samples we are using here for control purposes. It may be assumed that these differences result from variations in granulometric composition.

Figures 17 and 18 provide graphic illustration of the fundamental relation between shear strength and temperature variation. These graphs show that, the higher the temperature of the ground, the closer the curve holds to the axis of the ordinate and, on the other hand, reduc-

tion in temperature causes the curve to move away from that axis, and to become flatter and more drawn out.

It should be noted that it has not yet been possible to determine, experimentally, the relation that undoubtedly exists between shear strength and variation in moisture content. The demand for this information is such that it must be sought in the immediate future. Our experiments were too few to attain this object.

The samples we tested will now be sent to the laboratory, where they will be brought to the same temperatures and percentages of moisture content that they had when tested in nature. Then, their shear strengths will again be tested, but by laboratory methods. We will thus arrive at mutually comparable magnitudes for samples of undisturbed natural structure and of reorganized structure. This will, in turn, provide a basis for determining the comparability of laboratory and field research, a matter of the greatest importance when it comes to putting laboratory findings to practical use. The results of such comparison will also make it possible to determine the direction in which field research methods must be improved for the purpose of continuing this investigation in the future.

Igarka Permafrost Station
January, 1939

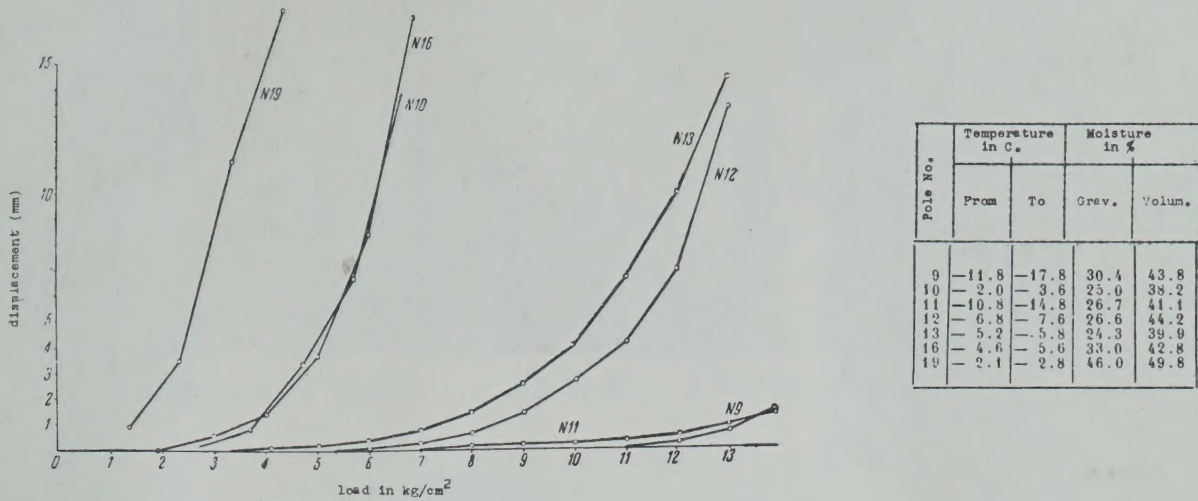


Fig. 17. Relation of the degree of displacement of frozen dust-silt ground of the first type to load.

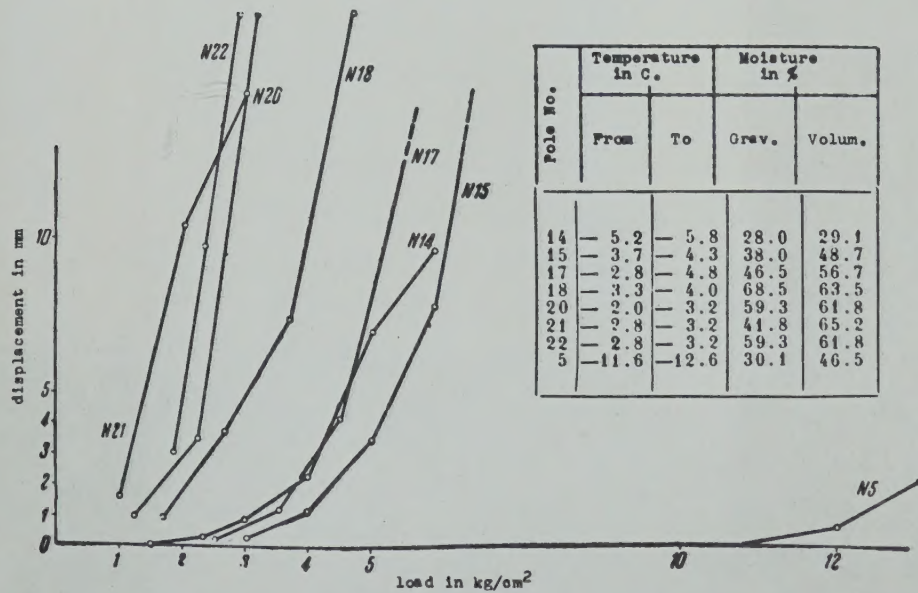


Fig. 18. Relation of the degree of displacement of frozen dust-silt ground of the second type to load.

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